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RETENTION OF MOTOR SKILLS: REVIEW

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J.D. Schendel, J.L. Shields,

and

M.S. Katz

INDIVIDUAL TRAINING & SKILL EVALUATION TECHNICAL AREA

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A summary of an extensive literature survey deals with the variables known or suspected to affect the retention of learned motor behaviors over lengthy no-practice intervals. Emphasis was given to research conducted by or for the military. The variables that may affect the retention of motor skills were dichotomized into task variables and procedural variables. The task variables that may underlie the long-term retention of motor skill include (a) duration of the no-practice period, or retention interval; (b) nature of the response ---

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required to accomplish a particular motor task; (c) degree to which the learner can organize or impose order upon the elements that define the task; (d) structure of the training environment; and (e) initial or "natural" ability of the learner in performance of a task without prior practice.

The procedural variables that may affect the long-term retention of motor skill include (a) degree of proficiency attained by the learner during initial training; (b) amount and kind of refresher training; (c) transfer of skills on one task to performance on another task; (d) presence of interfering activities; (e) distribution of practice during training; (f) use of part-task versus whole-task training methods; and (g) introduction of extra test trials prior to final testing.

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INDIVIDUAL TRAINING & SKILL EVALUATION TECHNICAL AREA

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Performance-Based Training

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FOREWORD

The Individual Training and Skill Evaluation Technical Area of the Army Research Institute for the Behavioral and Social Sciences (ARI) has actively pursued a program of research in support of the systems engineering of training. A major focus of this research is to develop the fundamental data and technology necessary to field integrated systems for improving individual job performance. Such systems include Skill Qualification Testing (SQT), job performance aids, training courses in schools and in the field, performance criteria, and management and feedback systems. This report summarizes the first step in the development of methods to assess and enhance the retention of job skills. This research is in response to the question, from the Army Training and Doctrine Command (TRADOC), "What is the required frequency of refresher training to maintain performance proficiency?" Work was accomplished by ARI personnel, under Army Project 2Q162722A777, FY 1978, "Individual Training Technology." Comments and editorial assistance were provided by Mr. J. Douglas Dressel and Dr. Joseph D. Hagman.

Joseph Zeidner

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RETENTION OF MOTOR SKILLS: REVIEW

BRIEF

Requirement:

As part of a major program on individual training for combat r s ness, to develop a sound information base for Army decisions necessary to insure soldiers' long-term skill proficiency, this review focuses on retention of motor skills.

Procedure:

This review is based upon a wide variety of data from an extensive literature survey of pertinent research. Although military-related findings were incorporated wherever possible, some of the experiments cited used tasks having little direct or obvious relationship with skills currently maintained within the Army. In addition, conflicting data and data pertinent to a more detailed understanding of the behavioral consequences of an extended no-practice period generally were skimmed over to lend coherence to this report. In so doing, an oversimplified picture of long-term motor memory and the variables that may affect it has been sketched. These constraints notwithstanding, a number of tentative conclusions have empirical support.

Findings:

1. The single most important determinant of motor retention is level of original learning. Knowledge of results and response-produced feedback are thought to contribute most to a trainee's original learning. Effectiveness of the knowledge of results increases with its availability and precision. Effectiveness of response-produced feedback increases with its quantity, for example, number of feedback channels and amount of practice, and fidelity.

2. Procedural tasks are forgotten in days, weeks, or months, whereas continuous control tasks typically are remembered for months or years.

3. Retention of skill decreases with time, depending on a host of variables, including the length of the no-practice period, the type of task, and the practice or interfering activities before or during the retention interval.

4. Retention is improved by increasing the amount of original practice. Overtraining or mastery training may be more cost effective than proficiency training, that is, training to one successful performance.

5. Time to retrain individuals to original performance levels is generally rapid, consistently less than half the original training time.

6. Learners apparently can impose organization upon psychologically unstructured tasks via the learning process. As a result, task structure is not an important variable for the long-term retention of well-learned responses, although it is an important variable for the retention of less well-learned responses.

7. Functional similarity of the training device to the actual equipment is a necessary and sufficient condition for learning procedural tasks.

8. Display-control relationships can influence the ease of motor learning and transfer and, to some degree, the quality of performance after a retention interval.

9. Augmented feedback can enhance performance by raising motivation, learning, or both.

10. Individual ability levels are important as determinants of retention insofar as they influence a person's time to achieve a standard level of performance. Individuals of higher initial ability tend to achieve higher levels of proficiency and retain skill at a higher level than individuals of lower initial ability.

11. Refresher training can serve as an effective source of new learning as well as a means for reestablishing forgotten responses. It also may provide a relatively simple means of improving on-the-job safety and performance.

12. Learning and retention are benefited by test-taking opportunities.

13. Positive transfer effects typically are observed when transferring between motor tasks. Although negative transfer is the exception, occasional intrusive wrong responses induced by past learning may have serious consequences for operators or equipment.

Utilization of Findings:

The conclusions and implications of previous research provide a firm basis for specific, ongoing programs to develop procedures that the Army can use to insure that its personnel remain job proficient over prolonged periods.

RETENTION OF MOTOR SKILLS: REVIEW

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RETENTION OF MOTOR SKILLS: REVIEW

INTRODUCTION

The mission of the U.S. Army during peacetime is to maintain a state of readiness to fight and to win the first land battle in event of war (39).* To accomplish this mission, Army personnel must be equipped with state-of-the-art weaponry and kept proficient in its use. Opportunities for sufficient post-mobilization training after the onset of war are not expected.

Establishing training procedures to develop proficient trainees is one problem; providing guidelines to maintain each individual's proficiency is another. These problems are interrelated and magnified by a resource-constrained environment. Cost-effective training demands that the Army identify procedures that enhance proficiency and minimize an individual's requirement for "refresher" training.

Purpose and Scope

This review seeks to develop a sound information base to facilitate Army decisions about training, transferring, and maintaining (i.e., long-term retention) skills that are critical for combat readiness. An information base would allow the Army to (a) develop procedures to maintain an individual's proficiency over prolonged no-practice periods, for example, weeks, months, or years; and (b) establish more accurately the optimal intervals for many refresher training programs.

The focus of this review is on the long-term retention of motor behaviors because well-learned, well-maintained motor behaviors (such as those involved in operating a tank, piloting an aircraft, shooting a rifle, or launching a missile) are necessary to achieve a guaranteed-effective retaliatory strike force. Of course, the findings are equally pertinent to the retention of less dramatic skills that are just as important for maintaining an effective Army.

Approach

This report presents a summary of an extensive literature survey dealing with the variables known or suspected to affect the retention of learned motor behaviors over lengthy no-practice intervals. The survey was accomplished using major documentation sources (i.e., Defense

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*Numbers in parenthesis refer to specific report citations in the References section.

Documentation Center, Human Resources Research Organization library, National Technical Information Service), data bases (Automated Data on Instructional Technology, Educational Resources Information Center, Psychological Abstracts), and a followup search of the psychological, military, and business/industrial literatures.

Research conducted by or for the military using military personnel as experimental participants was emphasized. Special consideration was given to research that employed evidently military-relevant tasks. Research on tasks having few real-world applications was included only if the results were practically indicative or suggestive.

RETENTION OF MOTOR SKILL: REVIEW

The variables that may affect the long-term retention of skilled motor performances were dichotomized into task variables and procedural variables. Task variables relate to the trainee or to the training/test environment, whereas procedural variables relate to the manner in which training, final testing, or both occur. Conclusions drawn about each are underscored in the text, with important reservations and exceptions noted. Directions for future research are suggested where the literature relating to the effect of a particular experimental manipulation is ambiguous.

The task variables that may underlie the long-term retention of motor skill include (a) duration of the no-practice period, or retention interval; (b) nature of the response required to accomplish a particular motor task; (c) degree to which the learner can organize or impose order upon the elements that define the task; (d) structure of the training environment; and (e) initial or "natural" ability of the learner to perform a task in the absence of prior practice.

The procedural variables that may affect the long-term retention of motor skill include (a) degree of proficiency attained by the learner during initial training; (b) amount and kind of refresher training; (c) transfer of skills from one task to another task; (d) interfering activities; (e) scheduling of practice during training; (f) use of part-task versus whole-task training methods; and (g) introduction of extra test trials prior to final testing.

Task Variables

Retention Interval

The retention interval is the period of no practice between the acquisition and subsequent test of a performance. The classical curve of forgetting, as depicted in Figure 1, is believed to apply to motor responses.

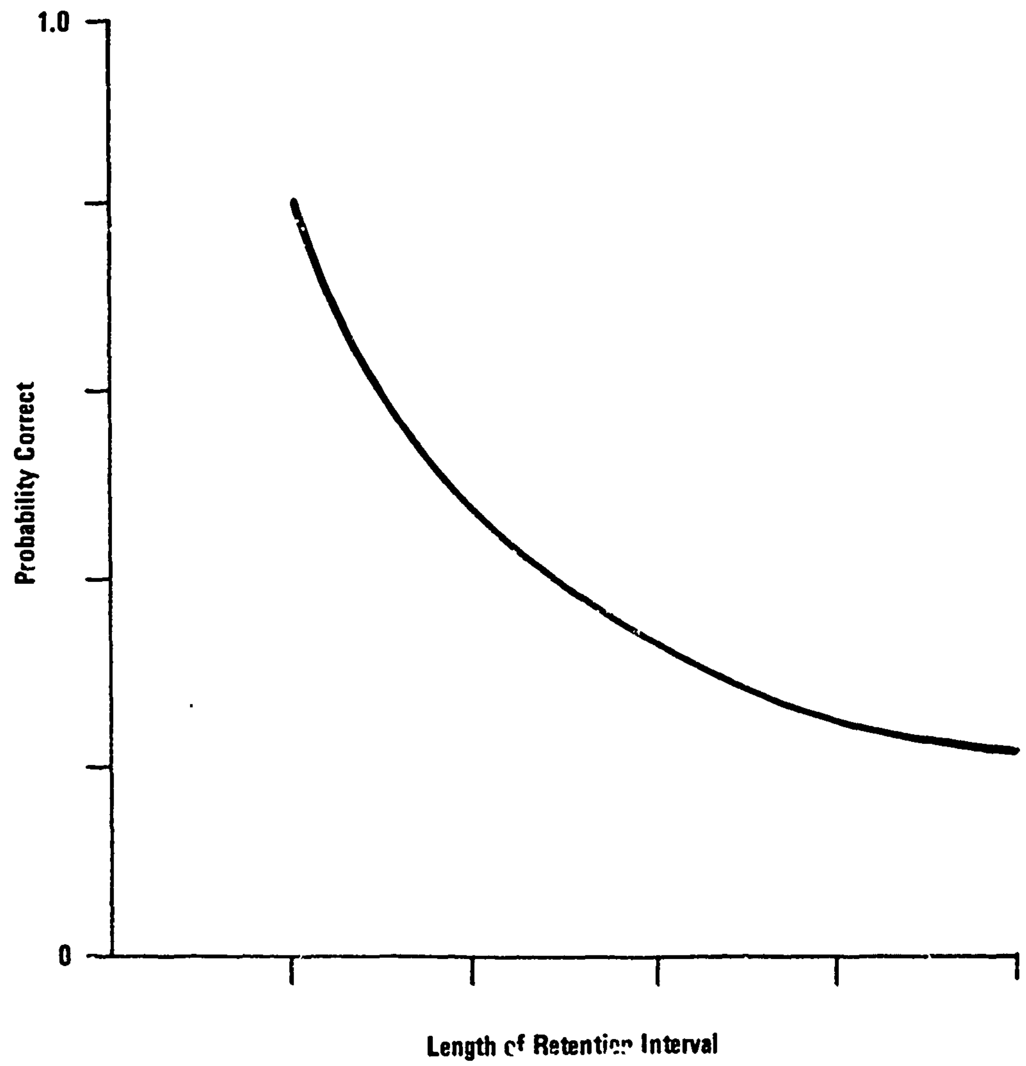

Figure 1. Hypothetical forgetting curve.

Note that the absolute amount forgotten increases with time, whereas the apparent rate of forgetting declines with time. Of course, the exact shape of any forgetting curve depends upon a host of variables (21) including (a) the amount of practice the learner receives (48,72); (b) the length of the interval between training and retention measurement (129); (c) the nature of the response to be retained (14); and (d) activities that interfere with acquisition or retention (75).

Nature of the Response

Motor responses are classified typically as either continuous or discrete, but probably no response is totally one or the other. We will define a response as continuous if it involves the repetition of a movement pattern that does not have a discernible beginning or end. The most commonly employed continuous task in studies of motor memory is tracking, presumably because it is the response activity that underlies vehicular control (2).

There are two types of tracking tasks, pursuit tracking and compensatory tracking. In pursuit tracking, the operator can see both the target to be followed and his tracking device or cursor. The operator's job is to keep the cursor aligned with the target so that the discrepancy between the two is nullified. Keeping a weapon sight (cursor) on a moving tank (target) is an example of a pursuit tracking task. In compensatory tracking, on the other hand, neither the target nor its position is displayed. The operator knows only the difference between an error-indicator and a fixed reference, and his task is to nullify this difference.

For example, error-nullifying principles are the basis of certain navigational instruments that signal the operator to begin directional (or attitudinal) corrections if he strays off the intended course. Also, the "leveling vials" used in field artillery may be regarded as a kind of compensatory tracking device. By compensating for the movement of an air bubble (error-indicator) floating within a glass tube mounted on the artillery piece, the gunner can adjust the artillery piece to a horizontal plane.

A response is discrete if it has a definite beginning and end and, typically, is quite brief in duration, for example, less than 5 seconds (117). Familiar examples of discrete responses include moving a gearshift, shooting a rifle, or throwing a hand grenade. Procedural tasks typically are composed of a series of discrete motor responses. Usually, the learner's main problem on each trial is selecting the correct response from a repertoire of possible responses rather than actually executing the response. The learner's main problem is determining "what to do" rather than learning "how to do it," for example, reassembling a carburetor or operating a radio communications system.

This need not always be the case, however, because certain procedural tasks such as playing the piano or executing the Manual of Arms not only require the performer to learn to select an appropriate series of responses but to learn how to execute them with the proper force and in the proper time sequence as well.

Procedural tasks and individual discrete motor responses are forgotten over retention intervals measured in terms of days, weeks, or months, whereas continuous movements typically show little or no forgetting over retention intervals measured in terms of months or years Although support for this proposition has been obtained in a wide variety of basic (129) and applied research settings, the most notable contributions have been made by investigators concerned with the long-term retention of piloting skills (51,99,100,127). Studies dealing with the maintenance of instrument flying skills (9,87), manned spacecraft flight operations (123,124,125), and lunar landing skills (38) consistently indicate that important procedural aspects of flight control deteriorate to unacceptable or unsafe levels over retention intervals measured in terms of weeks or months.

Although data are lacking with respect to the maintenance of Army job-relevant procedures, data on the maintenance of basic combat training skills (83,141), the preparation and firing of a Nike-Hercules missile (54,55), and gunnery proficiency in a combat air force (World War II) (114) support the contention that procedural proficiency cannot be maintained in the absence of regular practice.

Data on the retention of continuous movements come from studies of pursuit tracking (19,64,71,103,115,126), compensatory tracking (9,14, 18,48,87), and balancing (88,101,109,115). In contrast to the findings for procedural tasks, continuous movements generally are retained well over prolonged retention intervals, even in the absence of practice. For example, researchers, using a part-task flight simulator, found a 95% loss of procedural response proficiency over a 10-month retention interval, but found no effect upon the retention of continuous flight control responses (9). Others concluded that, although the forgetting of cockpit procedures over a 4-month retention interval could impair a pilot's flying efficiency and safety, this interval was not sufficient to degrade a pilot's continuous motor aircraft-control skills (87).

A number of hypotheses have been offered to account for the difference in retention of procedural and continuous movement tasks (2,92,129). They are as follows:

1. The verbal-cognitive nature of procedural tasks may make them easier to forget than continuous motor responses.

2. It is unclear what constitutes an individual trial during a continuous performance and, as a result, continuous responses may be overlearned and thus retained better than discrete motor responses.

3. Continuous responses may be retained better simply because they are more integrated or coherent than procedural tasks.

4. Retention differences between tasks may be partially due to the way errors are scored, that is, the methods used to score the retention of discrete motor responses may be relatively more sensitive to slight performance deviations than the methods used to index the retention of continuous responses.

Regardless of which interpretation finds support, the observation that procedural tasks are less likely to be retained at an acceptable level over a retention interval than are continuous responses has implications for Army training. In particular, regular refresher training must be provided for tasks that emphasize procedural knowledge. A similar recommendation was made to the Navy after a study was conducted on the forgetting of procedural and continuous instrument flying behaviors (87). Fortunately, procedural tasks are typically less expensive and simpler to train than are continuous responses because procedural tasks require little in terms of equipment beyond simple classroom training aids (54,55). Also, it is known that verbal cues and written job aids can facilitate the training and maintenance of procedural tasks (61,81). Techniques based upon this observation currently enhance on-the-job performance in the Army (the Integrated Technical Documentation and Training Program). Research efforts to make written job aids more accessible and easier to understand are likely to yield additional performance benefits.

Organization

Organization refers to the process by which the learner imposes order or structure upon the elements that define his task by establishing consistent relations among them (52). Evidence within the verbal (137) and motor (98,131,134,135) memory literatures suggests that tasks inherently amenable to learner organization are learned at a faster rate than less structured tasks. Under conditions of moderate learning, highly structured tasks also are retained at a higher level than less structured tasks. Once learning reaches an advanced stage, however, individuals apparently can retain less structured tasks as proficiently as highly structured ones.

For example, groups of individuals in one study were trained to perform two tasks simultaneously. The primary task was compensatory tracking, and the secondary task involved learning either a highly structured or less structured procedural sequence. Training was conducted for either 2 or 3 weeks and was followed by retention testing after either 1 or 4 weeks. As predicted, retention of the primary and secondary tasks by groups having the highly structured secondary task was superior to that of groups having the less structured secondary task. This effect, however, held only for those groups receiving moderate amounts of training. The structure of the secondary task did not affect the loss of tracking or procedural proficiency under greater amounts of training (94).

Thus, individuals apparently can impose structure upon psychologically unstructured tasks by organizing, but the act of organization takes time and practice. Indeed, the amount of time and practice required for a learner to organize some tasks may be too long for any reasonable training period. If sufficient initial learning opportunities exist, however, less structured tasks can be retained as well as highly structured ones.

Training Environment

A number of environmental variables have been identified (51) that may affect the long-term retention of military-related tasks. Among the variables are (a) the fidelity of training devices; (b) the compatibility of display-control relationships, (c) the specificity of task displays; and (d) augmented feedback.

Fidelity. The similarity between training devices and operational equipment can be viewed from two perspectives: physical similarity and functional similarity. Physical similarity, or fidelity, refers to the physical resemblance, in an engineering sense, between the displays and controls on a training device and those on the operational equipment. Functional similarity, on the other hand, refers to the "degree of representativeness" or "psychological realism" of a training device relative to the actual equipment (145).

Functional similarity is a necessary and sufficient condition for learning procedural tasks. For illustration, the acquisition and long-term retention of a 92-step procedural task (firing a Nike-Hercules missile) following training on a high-functional similarity drawing of the operational equipment has been shown to equal learning and retention following training on the actual equipment (54,55). A similar result was obtained using a complex procedural communication task (20). A comprehensive overview of the variables influencing transfer from training device to operational setting has been provided elsewhere (144,145).

Display-Control Compatibility. Certain display-control relationships appear to be more "natural" or "expected" for the human operator than others. This notion is based upon the observation that when several display-control relationships are possible for a given eye-hand coordination task, one relationship will lead to substantially better initial performance than the others (46). The interpretations offered for this effect suggest that compatible display-control relationships are more consistent with the learners' past experiences with the environment (1,120) or perhaps more consistent with the principles of human biomechanics than incompatible display-control relationships.

Examples of display-control relationships that typify those normally encountered in the environment include (a) moving a pointer to the right (display) by moving a lever to the right (control); (b) moving a pointer to the right by rotating a knob in a clockwise direction; and (c) moving a pointer downward by moving a lever forward (86).

The compatibility of display-control relationships influences the ease of motor learning and transfer (1,29,46) as well as the quality of performance after a retention interval (86). These results have implications for training and equipment design. Individuals training on high-compatibility equipment require less training to achieve and to maintain a satisfactory level of performance than individuals training on equipment having incompatible display-control relationships.

Indeed, it is suggested that the performance of individuals afforded a reasonable amount of training on equipment having incompatible display-control relationships may never catch up to the performance of individuals using high-compatibility equipment (46). The compatibility of display-control relationships may not pose serious problems during the performance of slow, self-paced tasks that allow a liberal margin for error. But it would be a mistake to expect optimal performance using equipment with incompatible display-control relationships in potentially dangerous (120), externally paced, or infrequently performed tasks.

Specificity of Task Displays. Most tasks, such as tracking, depend heavily upon the processing of visual information from a task display. At least during the initial stages of learning, the learner is forced to rely upon the visual cues he receives from the task display to guide his performance. Later in learning, however, the learner relies more on proprioceptive or other internal sources of information and depends less on the display and other external cues (16,49). This suggests that visual cues designed to supplement the information provided by the task display are informative early in learning and facilitate the learning process, but may be relatively uninformative once the learner has "internalized" the performance. This hypothesis was tested using a pursuit tracking task and task displays that varied in "specificity." Display specificity involved a numerical code and/or several grid systems that, superimposed on the face of an oscilloscope, permitted several levels of target-location cueing (136).

As predicted, the early acquisition of the tracking task was facilitated under conditions of high-display specificity. However, the specificity of the display did not affect the final levels of skill attained by the learners nor the 1-month retention. Apparently, later in learning, supplementary cues from a display do not provide information over and above that which is already provided by internal sources and consequently are not important as determiners of retention.

Augmented Feedback. Information about a response may be augmented, or supplemented, by delivering general instructions or perceptual cues to the trainee before, during, or after the response. For example, if the trainee can see each time he scores "a hit" on the standard task, then saying "hit" or flashing a light augments feedback. Little has been done to assess directly the effects of augmented feedback on the long-term retention of motor responses. The only experiment found on the subject failed to find any effect of supplementary auditory noise upon the acquisition or retention of a compensatory tracking task (33).

The effects of augmented feedback vary from task to task, both while the extra feedback is present and in tests after it has been removed (25). When augmented feedback is present, it often facilitates performance during training (29). This facilitation has been attributed to changes in motivation (22), learning (102), or both (69). To understand how these interpretations differ, see Figure 2. The figure presents the hypothetical performance data for two groups trained with and without augmented feedback that were transferred, or shifted, to common conditions after a rest interval. The three possible outcomes of the transfer test are illustrated in A, B, and C (117), and are explained below.

Certain variables, such as motivating instructions (47), stimulate or activate the learner to perform previously learned responses more vigorously, but they have no direct effect on the strength of those responses in memory. A variable that raises or lowers performance when present and whose effects disappear rapidly when removed is called a performance variable (result A).

For example, one experiment (22) involved the acquisition of an ele tronic antiaircraft gunnery task and the delivery of augmented visual feedback during training. Individuals in the control condition tracked each target plane using a group of dots as a cursor. Feedback was the visual error between the dots and the moving target plane. Individuals in the augmented feedback condition performed the same tracking task as those in the control condition, but they received extra visual cues (reddening of the target plane) when their responses were on target.

Individuals in the augmented feedback condition performed better during training than individuals in the control condition, but they did not learn more about the task than the controls. When subsequently required to perform in the absence of the supplementary visual cues, individuals in the experimental group performed no better than those in the control group.

Experience with some variables, such as organizational strategies (52,89), produces relatively permanent changes in performance. If the effects of this experience persist after the variable has been removed, the variable is said to be a learning variable (result B). For illustration, researchers using a pursuit tracking task in which trainees could

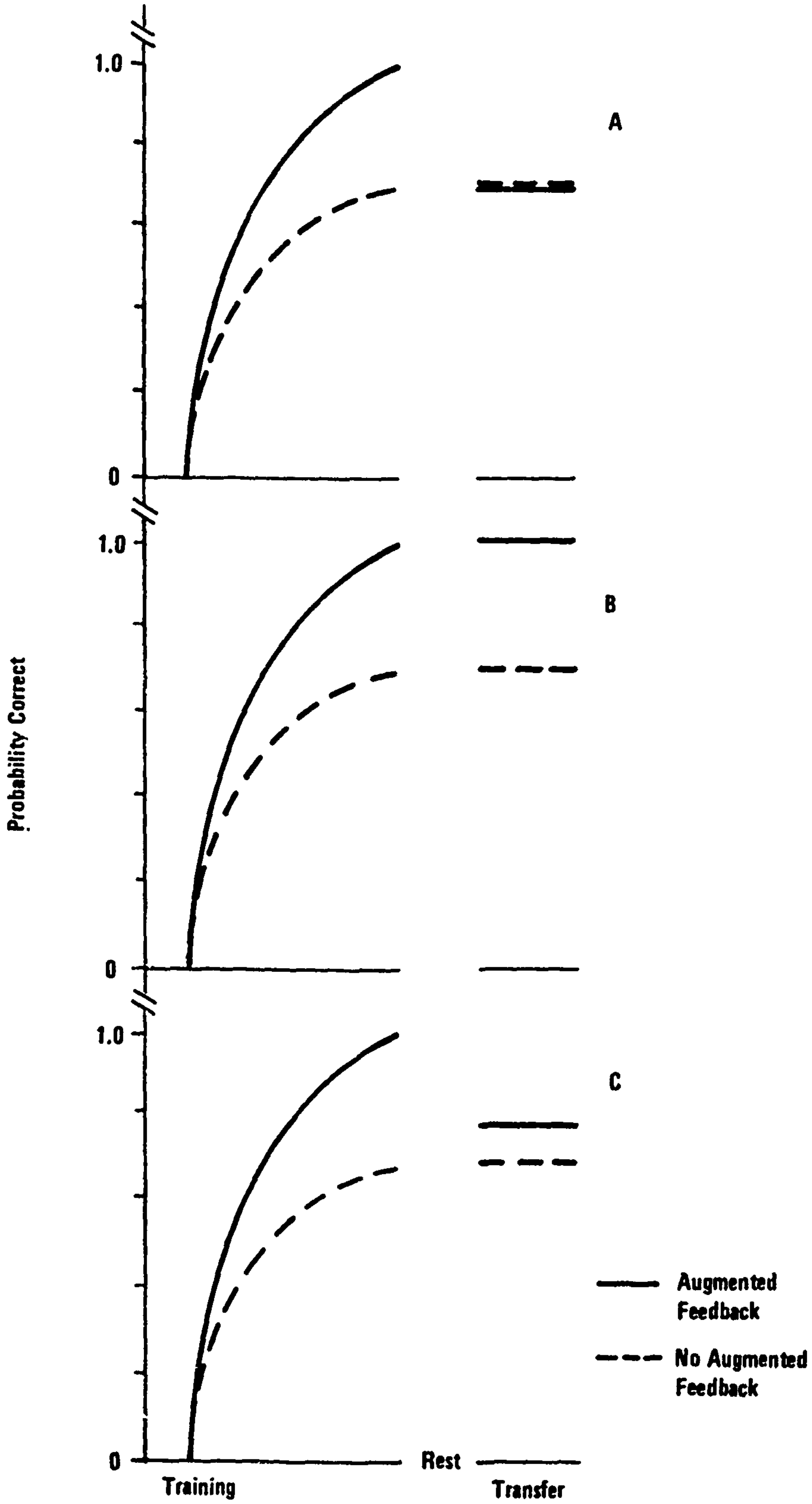

Figure 2. Hypothetical performance data for two groups trained with and without augmented feedback and then transferred to common conditions after a rest interval.

see if they were on target found that performance was enhanced greatly when feedback was augmented by a clicker that sounded when the trainees were on target. The authors attributed this enhancement to learning because the effect persisted after the clicker was removed (102).

Some variables, such as knowledge of results (76), appear to affect both performance and learning. For these variables, the dissimilarity between groups is reduced by a transfer test (result C). Some research indicates that augmented feedback may work in this way, at least in certain situations (69).

By definition, performance variables do not have a direct effect on learning or memory. An important reservation must be made, however. Any variable, such as augmented feedback, that can enhance an individual's motivation to perform a particular task also may induce him to practice harder or more frequently; few doubt the importance of practice as a variable for learning and memory (6). Thus, variables that raise (or lower) a person's motivation to perform a particular task also may act indirectly to determine what is learned and what is retained.

In summary, a variety of training procedures has been used to augment feedback. Some, but not all, produce lasting benefits. Some have no effect on performance. Some conceivably could produce performance deficits when withdrawn (25). It has been indicated that the transfer paradigm provides a basis for evaluating formally the impact of training variables such as augmented feedback on motor learning and performance. Informally, however, the following generalization appears to have some empirical justification as a guide for evaluating a training procedure:

> ...a subject must have some cues to the results of his actions if he is to perform accurately at all, and training procedures will be effective insofar as they help him to observe and use such cues as are inherent in the task for which he is being trained. They will fail insofar as they provide him with extra cues on which he comes to rely but which are not available when he changes from training to the actual job (143).

Individual Ability Levels

In the acquisition of motor tasks, individuals having higher initial ability levels generally require less time to attain a specified criterion than individuals having lower initial ability levels. This conclusion appears to generalize across a wide range of military (50,55,141) and nonmilitary (35,36,101) training conditions and a number of different operational definitions of the term initial ability.

Thus, research using eight training tasks ranging in complexity from a simple reaction time task (monitoring) to a combat plotting task problem solving (50), research using a 92-step procedural task (55), and research using 13 Basic Training Skills (141) all defined initial ability in terms of the trainees' Armed Forces Qualification Test scores and indicated faster learning by trainees who had higher mental aptitudes. Other studies, defining initial ability in terms of the learner's early performance on a to-be-retained balancing task (35,36) or using expert judgments of motor proficiency as an index of initial ability on five novel gross motor tasks (101) obtained analogous results.

In contrast, the weight of the evidence indicates that the rate at which motor proficiency is lost is not related to a performer's initial ability level (35,55,101,141). This is illustrated in Figure 3, which presents hypothetical forgetting functions for three groups of varying initial ability. Note that the functions are parallel to one another, suggesting a common rate of forgetting. Also note that individuals of higher initial ability achieve higher levels of proficiency during original training and retain their skill at a higher level over the retention period than individuals of lower initial ability (141). As a consequence, such individuals should require refresher training less frequently than persons of lower initial ability. Furthermore, refresher training can be shorter for persons of higher initial ability because they retrain to standards more quickly than persons of lower initial ability (55).

Procedural Variables

Level of Original Learning

A number of authors (48,51) have described the learner's level of original learning as the single most important determiner of motor memory. One study, using a three-dimensional flight-control task (48), found extremely high positive correlations (.80 to .98) between the learners' initial proficiency levels and later retention. This evidence is compelling because the strength of these correlations did not dissipate through time. The relationship between original learning level and retention remained high and stable over retention periods ranging from 1 month to 2 years.

Given the importance of original learning as a determinant of retention, some consideration must be given to the variables thought to contribute most heavily to the motor learning process. These are knowledge of results, for example, "right," "wrong," "too long," "too short"; and response-produced feedback, for example, proprioception, vision, and audition.

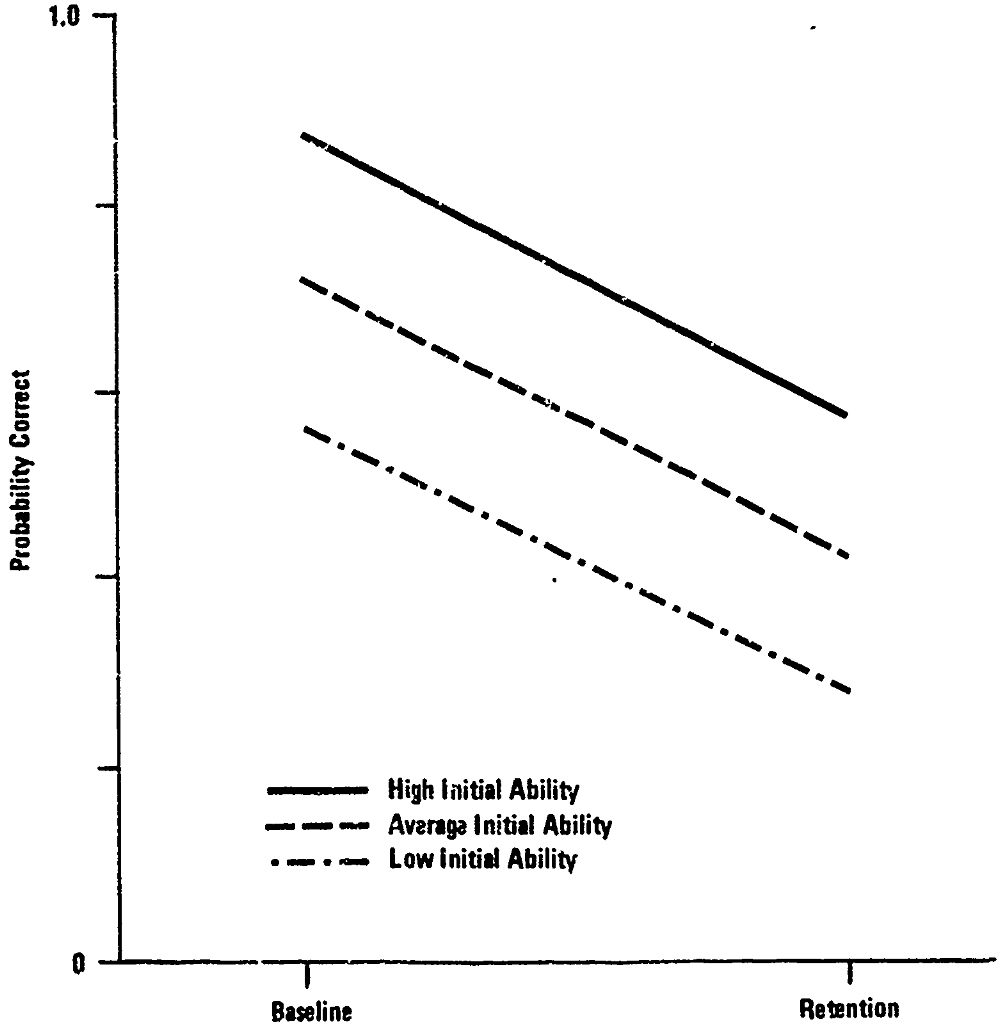

Figure 3. Hypothetical forgetting functions for three groups of varying initial ability.

Knowledge of Results. Knowledge of results refers to externally provided error information about the discrepancy between a learner's actual response and the intended response. Announcements such as "right," "wrong," "3 inches too far" are examples of knowledge of results. An account of the role of knowledge of results in motor learning is beyond the scope of this report; there are several literature reviews available on the subject (4,25,97,116). Two points from that literature, however, are especially pertinent:

1. The early acquisition of a skill depends heavily upon knowledge of results. Performance generally improves with knowledge of results and deteriorates, or shows no further improvement, when knowledge is withdrawn (24,96). Only later in learning, once a performance has become "internalized," may knowledge of results be withdrawn (or its absolute frequency reduced) without seriously impairing performance (96,118).

2. In the relationship between the amount of information provided by knowledge of results (its precision) and an individual's rate of learning and final level of performance, the consistent finding (133) has been that performance is facilitated by increases in the precision of knowledge of results, but only up to a point. If knowledge of results becomes too precise, that is, if the amount of information provided by knowledge of results is increased beyond that which can be processed by the learner within the time allowed, a decrement in performance will result (110).

In general, individuals who receive more and better knowledge of results require less training time and achieve a higher end-of-training performance level than those who do not. This suggests that any added effort to provide more or better knowledge of results to trainees would be worthwhile. It also suggests that special attempts must be made to facilitate the delivery of knowledge of results in situations that tend naturally to inhibit the presentation of its information.

For example, a major source of difficulty in training many team tasks is in detecting and correcting the errors of individual team members. Although a variety of factors contributes to this problem, it appears to stem primarily from the interactive effects of the team members' responding and the difficulties involved in simultaneously monitoring the behavior of several individuals (142). If techniques could be devised to facilitate the presentation of more or better knowledge of results in situations like these, a higher level of trainee performance is likely to be realized.

Response-Produced Feedback. The theoretical status of response-produced feedback during motor learning is still controversial (3,5,67, 68), but few doubt its practical importance for the acquisition of new motor responses. Most theorists (4,67) contend that early in learning, the learner uses knowledge of results in relation with the feedback

information he receives, for example, proprioceptive, visual, or auditory cues, to establish a memorial representation of how a correct performance feels, looks, and sounds. This representation is assumed to be weak initially, so the learner must depend heavily upon knowledge of results for information about the correctness of his performance (24,96).

Later in learning, however, after a stronger representation of the correct performance has been stored in memory, the learner can detect and correct movement errors by comparing the feedback qualities of his present performance with those of the stored representation. He no longer needs to depend upon knowledge of results for information about the correctness of his performance (96). This information is inherent in the feedback that he has received from past performances and that he receives from his present performance, and the information enables him to "know" when a performance is correct in the absence of knowledge of results.

The notion (4) that motor learning and performance depend upon the quantity, for example, number of feedback channels and amount of practice, and quality, that is, fidelity, of the response-produced feedback the individual receives has solid empirical support. The more response-produced feedback that the learner receives, the more accurate and confident he becomes in his responding (6,7,8,119). Also, retention is facilitated by increasing the amount of original practice or number of available feedback channels, for example, vision versus no vision. Evidence for this has been obtained under a wide variety of task conditions (87,94,134) and retention intervals (10,14,130).

Increased levels of original training facilitate retention, but is it cost effective to train beyond one successful performance, or is such overtraining excessive and wasteful?

Overtraining, or mastery training, is important, and it may be more cost effective than proficiency training, that is, training to some minimally acceptable level. Mastery training is known to enhance retention (58,85,92). This is a predictable result, but it has important implications for Army training policy. Currently, the Army relies heavily upon combinations of proficiency training and refresher training. The problem is that refresher training involves time, personnel, and equipment costs that cannot be minimized without first minimizing the need for refresher training. One way to do this is to extend original training. If future research should show that retention following mastery training equals or exceeds retention following an equal amount of proficiency training plus refresher training, a mastery training policy would appear to be the one to adopt.

The benefits of mastery training extend beyond improved retention. Theory (4,31,45,65,66) and data (27) suggest that the skilled performer is able to devote less of his total attentional capacity to an ongoing task than the novice. Mastery training thus frees the performer either to attend to other tasks or to concentrate upon different aspects of his main task.

Furthermore, there is evidence suggesting that mastery training may reduce the inhibitory effects of anxiety-arousing or stressful environments upon performance (79). Stated another way, the stressful environment that may distract the less-skilled individual and disrupt his performance may not seriously impair the highly skilled individual's performance. If this hypothesis is supported by future research, it has clear implications for Army training. In particular, the common belief may be incorrect that troops must be trained under simulated combat or other generally stressful conditions to react appropriately when placed in an actual combat situation. Mastery training alone may protect a soldier's performance from the interfering effects of an anxiety-arousing or hostile environment.

Physical practice is important in the acquisition and performance of motor tasks. However, there is evidence that the performance of some motor tasks can be enhanced as much or more by "mental practice" (104,105). One interpretation for this effect is that mental practice produces activity in the muscles involved in the performance of a task and that this activity transfers positively to performance. Although this interpretation has empirical support (105), another more reasonable interpretation is available. There is evidence that mental practice facilitates the cognitive, problem-solving aspects of motor learning. For example, predominantly motor tasks, such as tracking (128), show little benefit from mental practice, whereas tasks that require the learner to depend heavily upon intellectual, problem-solving skills, such as procedural tasks (105), generally reveal substantial benefits due to mental practice.

Also, some physical practice on a task enhances the effectiveness of mental practice. As physical practice continues, however, mental practice becomes increasingly less effective (122). This observation is consistent with the view that mental practice subserves verbal-cognitive processing during motor learning. It is during the initial stage of motor learning that verbal-cognitive activity is assumed to be prevalent (4,45, 65,66).

Although clear evidence on mental practice is difficult to obtain (105), closer scrutiny of the phenomenon is warranted. If, for example, mental practice alternated with physical practice can enhance or maintain performance on hazardous tasks, such as disarming explosives, or infrequently performed tasks, such as launching missiles, the potential benefits are great.

Refresher Training

Time to retrain individuals to original performance levels is generally rapid, that is, consistently less than 50% of the original training time (14,59,87). However, length of retraining time is much longer for (a) longer retention intervals (14,95), (b) more difficult tasks (73), and (c) for procedural tasks rather than continuous tasks (14,59,87). In

addition, highly trained individuals tend to require more training time to regain their old levels of proficiency than less-trained individuals (14,87). This latter result requires some clarification. Why should forgetting increase with training? Although this effect may seem counter-intuitive, it concerns forgetting in an absolute sense. Because highly trained individuals have more to forget, they have more to relearn.

Several investigations using military personnel have demonstrated that persons with practice during the retention interval perform better than those with no practice (72,123,124,125). For example, an experiment examining the effects of various practice strategies upon the long-term retention of simulated manned spacecraft operations (124) showed that performance on the procedural aspects of the task deteriorated to an unacceptable level within 1 to 4 months of no practice.

At the end of 1 month of no practice, trainees required five times longer to complete the procedural sequence than they did at the end of training. Additional performance decrements were not evident after 2 and 3 months of no practice. However, after 4 months of no practice, trainees required 17 times more time to complete the procedural sequence than they did at the end of initial training. In sharp contrast to these data, trainees afforded some form of practice during the retention interval showed no signs of losing their end-of-training proficiency levels on the procedural sequence over retention intervals measured up to 6 months.

Refresher training may provide opportunities for new learning. For illustration, researchers using a team of aerospace test personnel showed a substantial improvement over original training levels following refresher training 13 weeks after original training (38).

Refresher training techniques may improve on-the-job safety and performance (38,51). In particular, development of practice modules for safe practice of a dangerous or critical task immediately prior to actual task execution may result in fewer accidents and a higher quality output (123,124,125).

Warmup Activity. Closely related to the topic of refresher training in the literature on the effects of a preparation, or warmup period, on retention test performance (117). A warmup period can promote retention, but it depends upon the particular task and warmup activity. Many intervening activities are ineffective as warmup activities, and some result in poorer retention than a rest period (121). More research is needed on the effectiveness of various warmup activities on particular tasks to clarify this issue.

Some evidence (90) suggests that "neutral" tasks, involving activities unrelated to the task to be recalled, can be effective as warmup activities. If this is the case, it has practical implications for the Army. In particular, the introduction of a neutral warmup activity prior

to the performance of an infrequently performed, such as launching a missile, or dangerous task, such as combat, may prove an effective means of improving performance.

Transfer of Training

Transfer of training refers to the influence of past learning on new learning. Learning one task may help in learning or performing another task (positive transfer) or may interfere with the second task (negative transfer). For example, the responses acquired while learning to drive an automobile may alter the responses one makes when learning to drive a tank. Transfer depends upon the similarity of the stimuli and responses involved in tasks A and B (61,62,63), the individual's level of learning (1,42,61,75,78,145), and the difficulty of the tasks (17,61,77).

Positive transfer effects are observed typically when transferring between motor tasks, but the strength of the effects are usually small because of the differences between tasks and because of the effects of forgetting (1). The observation of negative transfer depends primarily upon how it is defined (23,61,62,63,75,80,82,117,145). If an overall decrement in performance is required for negative transfer, then the following conclusions are justified: Negative transfer is difficult to produce and, when produced, it obtains in negligible amounts and rapidly converts to positive transfer (23). If, however, negative transfer is defined in terms of the occurrence of an occasional, intrusive wrong response, then it may be a practical concern. Intrusion errors, although isolated, can occur within an overall context of positive transfer (75), and these errors may have serious consequences for the human operator or the equipment being operated. Thus, the pilot who is experienced with one aircraft may have no problem, relative to the complete novice, handling the controls of a different aircraft up to the point when a fatal error is caused by the pilot's previously established flight-control responses (63). Although such errors can be avoided by training within a controlled environment, such as use of a simulator, training is required.

Trace Decay and Interference

Trace decay and interference are theories of forgetting. Trace decay theory states that information deteriorates from memory solely as a function of time (2). One study indicates that information about discrete motor responses starts decaying as soon as it enters memory (129). However, there is no evidence about the decay of continuous motor information and the extent to which trace decay influences the retention of motor skill over prolonged no-practice intervals.

Interference theory states that forgetting is caused by competition from responses learned either before or after a response to be remembered. When the acquisition of task A degrades the retention of task B, proactive interference is said to have occurred. The acquisition of task A also may enhance the retention of task B. This is known as proactive facilitation. The inhibitory effect of task B on the retention of task A is known as retroactive interference. The converse of retroactive interference is known as retroactive facilitation.

Few investigations have been conducted of proactive (43) and retroactive (75,80,82) interference that used motor tasks and retention intervals longer than a few seconds. Based on the evidence obtained, it appears that interference effects, like overall decrements due to negative transfer, are difficult to produce and, when produced, persist typically for little more than a handful of trials. Also, these effects appear to be restricted to situations in which identical stimuli signal antagonistic responses (117). Unless two tasks employ identical stimuli and require antagonistic responses, facilitation effects can be anticipated generally.

Schedules of Practice

Continuous Tasks. Learning appears to be slower when practice sessions are longer and heavily massed than when they are shorter and occur at more comfortable intervals (13). However, most motor learning theorists (61,117,121) are reluctant to conclude that spaced practice is more conducive to learning and retention than massed practice. Rather, the theorists contend that individuals practicing under massed conditions may be more susceptible to the effects of boredom and fatigue than those practicing under spaced conditions. As a result, the relatively poor performance of individuals in the massed condition may not reflect the amounts that they are actually learning. To support this contention, a substantial body of evidence (11,74,103) indicates that persons who are given rest after practicing under massed conditions can demonstrate levels of learning equivalent to those achieved by individuals practicing under spaced conditions.

Although there is generally little or no dissimilarity in the retention of groups trained under massed and spaced practice schedules, an important cautionary note is necessary. The acquisition of dangerous or highly fatiguing tasks may be impaired under massed practice conditions (117). That is, learning and performance may be hindered if the task is too dangerous or too strenuous to be attempted repeatedly in the absence of rest. In support of this hypothesis, the literature on vigilance indicates that humans cannot maintain a high level of performance in tasks that require continuous sustained attention (32). If rest opportunities are not provided, individuals lose their motivation to perform or show involuntary lapses of attention. If these lapses of attention accumulate, they may hinder the early learning of persons in the massed practice condition relative to persons in the spaced practice condition (61).

Discrete Tasks. In contrast to continuous tasks, the scheduling of practice apparently affects neither the acquisition nor performance of discrete tasks (37,117). No data are available concerning the effects of different practice schedules on the acquisition and performance of procedural tasks. However, it is likely that the effects of distribution are quite small and relatively unimportant when measured against the influence of other learning variables. This hypothesis stems from both the observation that the distribution of practice typically has little or no effect upon the acquisition of lists of verbal items having some degree of internal organization (138,139) and from the common belief that the motor responses involved in most procedural tasks have a strong verbal component (2,117). In the absence of further research, however, there is no way to confirm or deny this hypothesis.

In summary, the manner in which practice occasions are arranged temporally generally does not have a strong effect upon individuals' final level of original learning. The number of practice occasions offered is an important variable. Therefore, in limited-duration training programs, better retention should result using massed rather than spaced practice schedules. The fact that massing allows more trials per unit time and hence more opportunity for initial learning is the basis for this interpretation (23,117).

Whole- Versus Part-Training Methods

The trainee may learn a task by practicing the entire task from the beginning--whole practice--or by dividing the task into a number of discrete parts--part practice. In the part-practice situation, the learner practices each part separately or in conjunction with other parts and later integrates the parts to form the whole task. Obviously, there is no way to define the meaning of the terms part or whole because specification depends upon the particular task (61).

Four general categories of variables seem to have an effect upon the effectiveness of part- versus whole-training methods (91):

1. Task to be learned, for example, organization, difficulty;

2. Learner variables, for example, intelligence, age, experience, preference;

3. Training situation, for example, amount of practice; and

4. Performance measures, for example, time or trial scores.

Task to Be Learned. The effectiveness of part- as opposed to whole-training methods varies with the difficulty of a task's independent subtasks and the degree to which the subtasks are interrelated (53,61,117, 121):

1. It generally is easier to learn simple to moderately difficult tasks using whole-training methods rather than part-training methods, whereas the opposite is true for more difficult tasks (121).

2. Tasks requiring high coordination and timing of their serial-motor components are learned faster using whole-training methods. In contrast, part-training methods tend to be more effective for tasks that can be divided into meaningful independent subtasks (30,93).

3. There appears to be an interaction between task difficulty and task organization that influences the relative effectiveness of part- and whole-training methods. Thus, training for tasks of high organization becomes increasingly more effective with whole practice as task difficulty increases. On the other hand, training for tasks of low organization is increasingly improved by part practice as task difficulty increases (91,93).

Learner Variables. There is some evidence that more intelligent individuals may learn and hence retain more using whole- rather than part-training methods. Evidence for this conclusion comes from a study of the use of whole- and part-training methods to teach rifle marksmanship to Army Basic Trainees (84). Although the whole-training method was found to be superior in slow-fire routines for all trainees, the more difficult task of sustained fire was facilitated when the whole method for only trainees of above-average intelligence was used.

Individuals who are older (school-age subjects), who have more task-related experience, or who are performing a preferred task also tend to learn faster and better when whole- rather than part-training methods are used. These results have been interpreted in terms consistent with the hypothesis that less difficult tasks are more amenable to whole- rather than to part-training methods (91). This is a reasonable interpretation. Presumably, a task is simpler for older, more intelligent, or more experienced persons. To the extent that a person's preference to perform a particular task may be related to task difficulty, it may be viewed as another condition under which task difficulty influences training-method effectiveness.

Training Situation. As training continues, learning is increasingly benefited by whole practice (91). Apparently, this is another instance in which task difficulty is the variable underlying the effect. Practice facilitates the ease of a performance, causing later learning to be more amenable to whole- than to part-training methods.

Performance Measures. Different results are sometimes obtained when different performance measures are used. In particular, time scores occasionally favor part-training methods whereas trial measures sometimes favor the whole method. However, this effect appears to be artifactual (91).

Part-Whole Learning and Long-Term Retention. A search of the whole- versus part-training method literature for information about the impact of this training variable upon long-term motor memory was almost in vain. One set of experiments was found on part-whole learning and long-term motor memory (112,113). The author failed to show any differences, however, between conditions during original learning and retention.

Although retention should benefit from the training method that yields the higher original training level, both part- and whole-training methods may produce substantially equivalent training outcomes (112,113). Under these conditions, it may be more cost effective to use the part method. The part method typically employs, or can employ, simulators (9) that are usually lower in operating costs, more adaptable to training requirements, and less hazardous to the operator (140) than the operational equipment.

Additional Test Trials

Performance tests have been perceived traditionally as tests of learning or memory. It is becoming increasingly clear, however, that test trials themselves contribute to the learning process. Evidence concerning the effects of additional test trials, without knowledge of results, comes primarily from studies of verbal memory; at least two conclusions appear justified on the basis of it.

1. Memory is facilitated greatly by the addition of a test trial given prior to final testing. For example, investigators studying the long-term retention of verbal paired-associates found that the addition of an immediate test, after 10 paired presentations of the stimulus and response members of an item, reduced error frequency by nearly 50% as compared to 10 paired presentations without the retention test. In addition, long-term retention, as measured by the individuals' response latencies as well as their error frequencies, showed further improvements when five test trials were introduced prior to the final retention test (12). Converging support for this conclusion comes from a host of experiments, many of which have been reviewed elsewhere (15,108). In general, final test performance is faster (44), more accurate (26,106,107), and more stable (34), and relearning is quicker (108) when additional test trials, without knowledge of results, are provided.

Evidence is lacking concerning the effects of additional test trials, without knowledge of results, upon the retention of motor skill. Indeed, this survey uncovered only one experiment on the topic. It involved the acquisition and retention of a simple linear movement (41). Contrary to expectations derived from the verbal learning literature, the introduction of additional test trials during the retention interval did not aid retention. In fact, individuals in the experimental groups became increasingly less accurate, that is, more variable, over successive test trials.

It may be that additional test trials introduced during the retention interval do not enhance motor retention, but this seems very unlikely. As has been indicated, additional test trials have clear, beneficial effects upon the retention of verbal materials. There is no apparent reason to expect that these effects differ across response classes. It would seem more likely that the experimental design employed by these authors was incapable of identifying the effects of additional test trials upon motor retention. More research on this issue clearly is indicated.

2. Additional test trials are equally if not more beneficial to learning and retention than study opportunities. A recent experiment using a verbal memory task illustrates the effectiveness of additional test trials as a variable for long-term retention (60). Researchers tested groups of individuals for the retention of a list of words after a 48-hour retention interval. One group was exposed to the list four times before the final retention test, that is, study-study-study-study-test. A second group received a single presentation of the list and three test trials prior to the final retention test, that is, study-test-test-test-test. Even though the former group was permitted four times more study time on the list than the latter, the final retention of the latter group was far superior to that of the former group.

A number of interpretations have been offered to account for the facilitating effect of additional test trials on the retention of verbal material (70). Perhaps the most plausible of these is that additional test trials enhance the recovery of information from memory either by facilitating its organization (28,40,111) or by enabling the learner to develop a plan, or strategy, to retrieve the appropriate information at the time of testing (57). It is also likely that test trials help the learner to determine where learning is incomplete. Thus, on a given training trial, the learner may recognize material he missed on the previous test trial and concentrate on that rather than devote further attention to previously learned material (70,132).

The observation that additional test trials may be more beneficial to learning than additional study time has important practical implications for training. In particular, it may be possible to reduce overall training time, produce a more effective trainee, or both, simply by affording the trainee more test-taking opportunities. Tests of the generality of this hypothesis are necessary to determine whether additional test trials facilitate the retention of a wide variety of tasks. The Army Research Institute has begun research on this issue.

SUMMARY

This review is based upon a wide variety of data. Although military-related findings were incorporated wherever possible, some of the experiments cited used tasks having little direct or obvious relationship with skills currently maintained within the Army. In addition, conflicting

data and data pertinent to a more detailed understanding of the behavioral consequences of an extended no-practice period generally were skimmed over to lend coherence to this report. In so doing, an oversimplified picture of long-term motor memory and the variables that may affect it has been sketched. These constraints notwithstanding, a number of tentative conclusions have empirical support:

1. Discrete motor responses, particularly those involved in procedural tasks, are more likely to be forgotten over a no-practice period than are continuous motor responses.

2. Retention of skill is a decreasing function of time, and the shape of the function depends upon a host of variables, including the length of the no-practice period, the type of task, and the availability of practice or the presence of interfering activities before or during the retention interval.

3. Apparently, learners can impose organization upon psychologically unstructured tasks via the learning process. As a result, task structure is not an important variable for the long-term retention of well-learned responses, although it is an important variable for the retention of less well-learned responses.

4. Functional similarity is a necessary and sufficient condition for learning procedural tasks.

5. Display-control relationships can influence the ease of motor learning and transfer and, to some degree, the quality of performance after a retention interval.

6. Visual cues designed to supplement the information provided by a task display are informative early in learning and may facilitate the learning process. Later in learning, however, these cues become relatively uninformative and unimportant as determiners of retention.

7. Augmented feedback can enhance performance by enhancing motivation, learning, or both.

8. Individual ability levels are important as determiners of retention insofar as they influence a person's rate of learning and final level of performance. Individuals of higher initial ability tend to achieve higher levels of proficiency and retain skill at a higher level than individuals of lower initial ability.

9. The single most important determinant of motor retention is level of original learning. Information obtained from knowledge of results and response-produced feedback is thought to contribute most heavily to a trainee's rate of learning and final level

of performance. Information provided by knowledge of results increases with its availability and precision. Information provided by response-produced feedback increases with its quantity, for example, number of feedback channels and amount of practice, and quality, that is, fidelity.

10. Refresher training can serve as an effective source of new learning as well as a means for reestablishing forgotten responses. Refresher training also may provide a relatively simple means of improving on-the-job safety and performance.

11. Learning and retention are benefited by test-taking opportunities.

12. Occasional, intrusive wrong responses induced by past learning may have serious consequences for the human operator or the equipment he is operating.

CONCLUSIONS

Returning to the main issue: What procedures can the Army reasonably use to insure that its personnel remain job proficient over prolonged periods of no practice?

More basic and applied research is clearly indicated. Suggested during the course of this review were a number of issues and avenues for research aimed at increasing training effectiveness. Because long-term retention appears to depend so heavily upon a trainee's original learning level, this would seem, at least initially, to be the most direct and effective means of attacking the issue of skill maintenance in the Army.

Stepping up research efforts is not all that needs doing to foster a more proficient Army trainee. Research has value but only insofar as it permits inferences to be drawn about the effects of particular variables upon the retention of particular performances. Research does not enable one to determine when a given individual or team lacks job proficiency. This fact is of fundamental importance if the Army is to have a cost-effective refresher training program.

More emphasis must be placed upon the use of local individual proficiency examinations, for example, some more frequently administered variant of the Skill Qualification Test. This would seem to be the simplest and most economical program to adopt. Those who fail to demonstrate proficiency can receive refresher training tailored to their specific needs. Those who retain their proficiency can be freed for other duties.

Individual performance evaluations can provide other benefits to the individual trainee as well as to those in supervisory positions. For example, the Job Performance Evaluation program currently being developed by American Telephone and Telegraph Company (56) uses a uniformly applied set of performance standards to judge objectively the quantity and quality of work of individual employees. The employee is informed exactly what he is being held accountable for and is told specifically how his performance compares with management's expectations. As a result, the employee knows deficiencies in performance and can modify the direction and level of his efforts.

In addition, supervisors receive precise information about the productivity of individual subordinates by which they can (a) modify and thereby improve training programs; (b) increase the validity of procedures used to select and to promote employees; and (c) improve their own job performance by learning more about the progress of their subordinates as well as the progress of their work group as a whole.

The assessment of American Telephone and Telegraph's evaluation program is only beginning: The success of the program to date is based primarily upon anecdotal reports of improved employee productivity and morale. Nevertheless, their program, or one like it, appears to be particularly suited to many Army requirements in this area and definitely warrants the Army's consideration.

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1 NAVAIRSTA, Norfolk, ATTN: Safety Ctr
1 Nav Oceanographic, DC, ATTN: Code 6251, Charts & Tech
1 Center of Naval Anal, ATTN: Doc Ctr
1 NavAirSysCom, ATTN: AIR–5313C
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1 AFHRL (DOJN) Lackland AFB
1 HQUSAF (INYSD)
1 HQUSAF (DPXXA)
1 AFVTG (RD) Randolph AFB
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1 Air Force Academy, CO, ATTN: Dept of Bel Scn
5 NavPers & Dev Ctr, San Diego
2 Navy Med Neuropsychiatric Rsch Unit, San Diego
1 Nav Electronic Lab, San Diego, ATTN: Res Lab
1 Nav TrngCen, San Diego, ATTN: Code 9000–Lib
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1 NavTrngEquipCtr, Orlando, ATTN: Tech Lib
1 US Dept of Labor, DC, ATTN: Manpower Admin
1 US Dept of Justice, DC, ATTN: Drug Enforce Admin
1 Nat Bur of Standards, DC, ATTN: Computer Info Section
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1 Mil and Air Attache, Austrian Embassy
1 Centre de Recherche Des Facteurs, Humaine de la Defense Nationale, Brussels
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1 C/Air Staff, Royal Canadian AF, ATTN: Pers Std Anal Br
3 Chief, Canadian Def Rsch Staff, ATTN: C/CRDS(W)
4 British Def Staff, British Embassy, Washington
1 Def & Civil Inst of Enviro Medicine, Canada
1 AIR CRESS, Kensington, ATTN: Info Sys Br
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